Ocean Acoustics Turbulence Study

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LONG-TERM GOALS

Classify the acoustic scatter from media versus medium variability in the ocean, and measure the three-dimensional wave number spectrum of scalar and vector ocean turbulence using high frequency broadband multi-static acoustic scatter.

OBJECTIVES

To examine and quantify the nature of acoustic scattering from thermally generated scalar microstructure using high frequency acoustics and far-field weak scattering theory, and specifically to investigate the role of anisotropy of the scattering field upon the statistical nature of the common Bragg wave number comparison technique.

APPROACH

The approach applies and extends theoretical and laboratory techniques of previous work to examine more closely the prediction made by application of far-field weak scattering theory to a thermally generated buoyant plume.[1,2] High frequency broad bandwidth multi-static acoustic scattering measurements are made in a controlled laboratory environment from a thermally generated turbulent plume. Far-field weak scattering theory is used to describe the complex acoustic scatter. The issues being addressed are the conditions under which the instantaneous common Bragg wave number comparisons are in agreement. This is a result of the fact that far-field weak scattering theory predicts the common Bragg wave number comparison to agree for spectral comparisons with overlapping wave numbers, yet data indicate that instantaneous comparisons are not always satisfied.

However, if instead of examining the instantaneous received pressure field associated with scattering from the turbulent plume, the ensemble average of the intensity is used, the Bragg scattering condition may be recovered. This results when the variability field has a sufficiently small degree of anisotropy. The scattered field can then be interpreted in terms of the wave number spectrum of the temperature field. It should be noted that for this case, since the scattering field is distributed throughout the scattering volume, the effective "average" spatial scale of scattering must be much smaller than r_F, the Fresnel radius.

Far-field scattering requires that the size of the scatterer in the direction of the Fresnel radius be smaller than the Fresnel radius. Thus the degree of symmetry of a scatterer or, in the case of statistical

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quantities such as turbulent spectra, the degree of anisotropy of an ensemble of scatters will play an important role in determining whether the Bragg scattering condition can be used to develop a Fourier integral relationship between the received acoustic field and the scattering field. If l is a characteristic scale of the scattering in the direction perpendicular to the Bragg wave number then the criteria for far-field Bragg scattering is $l << r_F$.[3] The correlation length of the temperature anomalies for the turbulent plume considered here in the direction perpendicular to the plane of scattering (the "z" direction) and thus along a Fresnel radius can be qualitatively estimated to range between 0.1 cm $< l <$ 2.0 cm. Thus, for the work described in this report, l can be of order the Fresnel radius and eddies of the turbulent thermal plume may not satisfy the criteria of having a sufficiently small spatial scale in the direction of a Fresnel radius at any instant of time. This may be why the previous (unpublished) data set indicated a breakdown of the Bragg scattering condition. However if the variability of the temperature field eddies within the thermal plume are turbulent-like at the scale of the Bragg wavelength, then it is expected that the ensemble-averaged received pressure field may result in the far-field Bragg scattering condition to be satisfied and a Fourier integral recovered. This can occur because in a turbulent field although individual turbulent eddies may have a particular orientation, on average, their orientation is more random and averaging is expected to bring down the degree of asymmetry or anisotropy. Note that in classical turbulence theory at scales of the inertial subrange and smaller[4] the three-dimensional spectrum of the field is isotropic even though individual eddies are not necessarily (and indeed in general are not) spherically symmetric. Thus for isotropic turbulence the far-field scattering condition and the Bragg scattering condition can then be recovered and the spectrum of the temperature field estimated acoustically. Realistic turbulent-like fields may have anisotropy but it is still expected that the degree of anisotropy will be less than the degree of asymmetry of an individual instantaneous eddy. Thus for a turbulent field the scale or wave number of the scattering will play a critical role in determining this issue of isotropy. If the Bragg wave number is of order and/or greater than a characteristic inertial subrange wavenumber[4] it is expected that isotropy or near isotropy should hold. Alternatively, acoustic scattering provides a mean of assessing whether in fact the turbulent field has this level of isotropy.

WORK COMPLETED

A set of high frequency broadband multi-static scattering measurements from a thermally generated buoyant plume were made, including coincident and near simultaneous point temperature time series measurements.

RESULTS

In regions where common Bragg wave numbers between measurements taken at adjacent scattering angles exist, the magnitude of the wave number spectrum between the channels is in good agreement but do contain instances of divergence between the channels. Pronounced structure is present in the spectrum and is typical for scattering from the turbulent plume. The nulls in the wave number spectrum can be as much as 30-40 dB below the mean spectral value. It should be noted that ping-to-ping records of the spectrum tend to remain highly coherent. Deep nulls indicate that the turbulence has a low Reynolds' number and thus is not fully developed.

However, the results validate the prediction made by the far-field weak scattering theory when ensemble averaging is employed to calculate the wave number spectrum. The mean value of the three-dimensional wave number spectrum yields a continuous spectral line that falls off slightly faster than the −11/3 power law expected for classical turbulence.[4] This is not an unexpected result given the structure of the spectrum showing the nulls and the low value of the Reynolds number. This result indicates that the complex acoustic scatter can be used to make quantitative measurements of the medium fluctuations and actually represents the three-dimensional wave number spectrum of the scattering field.

The wave number – frequency spectrum of the turbulent plume is determined by taking a Fourier transform over the time series of common Bragg spectral estimates for a matrix of the combined three channels of data and is shown in Fig. 1.

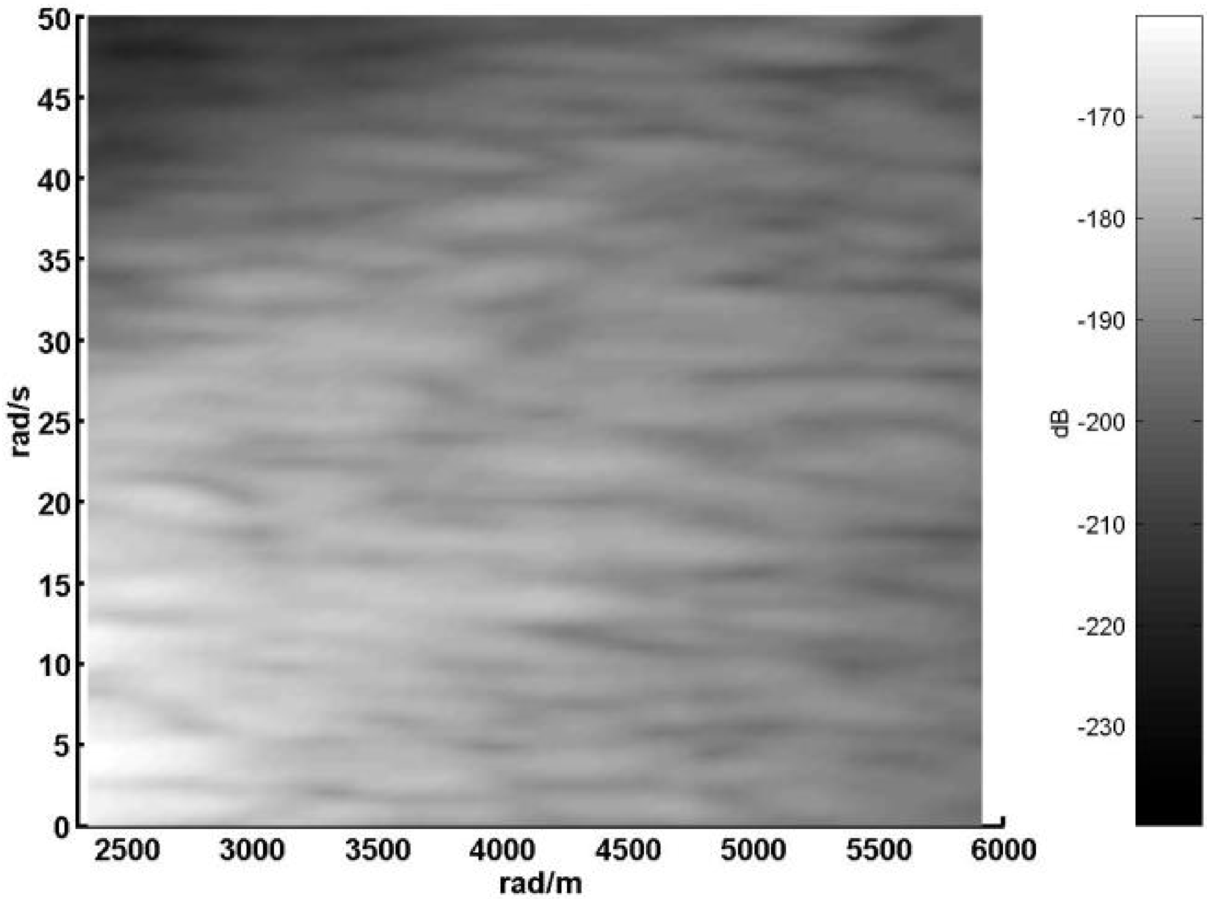

Figure 1. Wave number - frequency spectrum of index of refraction fluctuations from a turbulent plume.

To compare the acoustically derived results with those from the temperature probe we need to convert the acoustic wave number frequency spectrum to a frequency spectrum since the temperature probe is limited to a point time series measurement. The assumption that is made is that of spatial isotropy over the Bragg wave number range (which corresponds to mm range spatial scales), which allows integration of the acoustically estimated three-dimensional wave number – frequency spectrum. The result is shown in Fig. 2.

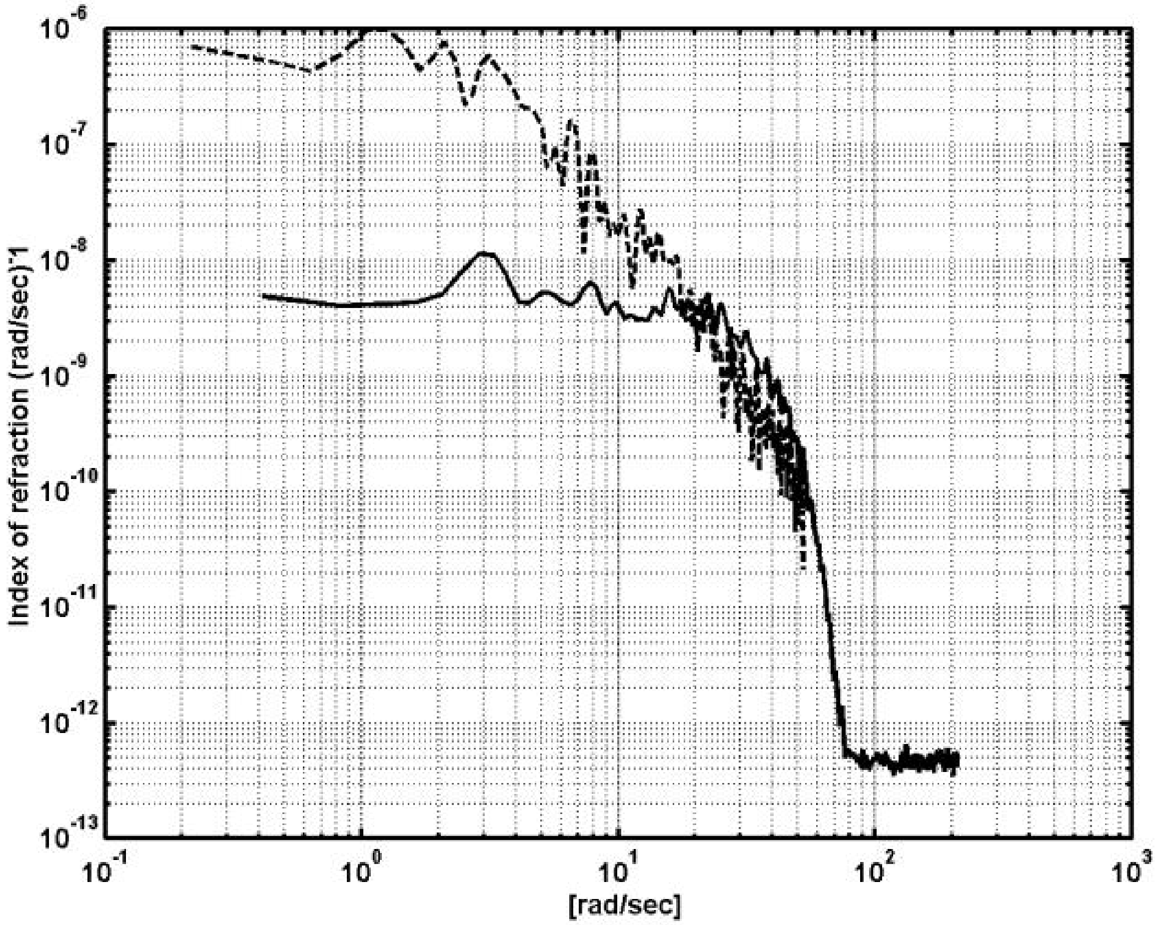

Figure 2. The estimated one-dimensional spectrum of the index of refraction for the turbulent plume case. The dashed curve is calculated by using a thermometer with a correction for the high frequency response included. The solid curve is the acoustically derived one-dimensional spectrum, calculated by integrating over the "three-dimensional" wave number space assuming isotropy.

Between 20 and 50 rad/s there is remarkably good agreement between the two types of measurements, both in terms of magnitude and roll-off. If the acoustic signal were extended to lower wave numbers by either incorporating smaller scattering angles in the common Bragg wave number configuration or by using lower acoustic frequencies, the lower frequency part of the index of refraction (temperature) field as measured by the mechanical probe would be able to be estimated.

Although the acoustic scatter is a spatial measurement and the temperature probe is a point measurement, given the reasonable assumption of isotropy, this comparison is a "ground-truth" for the acoustic estimate and indicates the utility of the acoustic scatter from medium variability.

IMPACT/APPLICATIONS

Under the conditions that satisfy the far-field weak scattering theory, the complex acoustic scatter is capable of providing quantitative information on medium variability. This could potentially provide a means for remote and rapid environmental characterization.

TRANSITIONS

RELATED PROJECTS

REFERENCES

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[4]G. K. Batchelor, Homogeneous Turbulence (Cambridge University Press, New York, 1967)

PUBLICATIONS

Oeschger, J., Goodman, L., " Acoustic scattering from a thermally driven buoyant plume revisited," (submitted to JASA)

PATENTS

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